THE ECOLOGICAL RELATIONS OF THE VEGETATION OF WESTERN TEXAS.

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY. XXX.

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(WITH TWENTY-FOUR TEXT FIGURES)

WESTERN Texas has been a choice field for botanists from the earliest days, always having been accessible through the numerous army posts and government surveys. For this reason the flora early became fairly well known through numerous contributions describing the country and its vegetation, and from descriptions of species, culminating in the *Botany of Western Texas* by Professor Coulter. Since that time, the study of plants in their natural environments has enriched botanical thought, and it seems opportune to take up again the flora of western Texas and to apply to it the new methods.

A further reason for presenting the plant life of Texas as the product of its environment lies in the growing tendency to rely upon such study to furnish a rational basis for the exploitation of plant life in agriculture, horticulture, forestry, agrostology, and various other economic fields. The great diversities of climatic factors, of soils, and of physiographic conditions in the Texas region make it necessary to find the results of these factors as recorded in plants already occupying the field, that they may serve as a guide in attempting to introduce new ones. The statement that the flora of western Texas early came to be fairly well known is true only of pteridophytes and spermatophytes, for the bryophytes and thallophytes have scarcely been noticed thus far.

The present paper aims only to clear the field a little, preparatory to its cultivation along special lines; and because it is a very large field, with much to be done, it offers a strong

invitation to colaborers. There is no special reason for excluding eastern Texas from this discussion, other than that the whole field is too large for a single paper. During a residence of more than three years, the writer has personally explored a great deal of the state, and yet there are vast areas he has not seen, and of which he cannot speak from first-hand knowledge. Hence even this general analysis of the vegetation must contain inaccuracies and misjudgments, which only a detailed survey of the provinces concerned will correct.

With the opportune appearance of Professor Hill's *Physical geography of the Texas region*[1] the task of presenting the climatic and especially the physiographic and geological factors has been much lightened, and by his courtesy a very free use has been made of this Texas folio. He has given much help also in the way of suggestions and photographs, which is herewith gratefully acknowledged. Dr. V. Havard's *Report of the botany of southern and western Texas*[2] has also been of great service.

The order followed is to discuss first the climatic factors in their relation to the vegetation of the region, and second the vegetation itself under several general types of association (plant formations), together with the factors of geology, soils, and physiography (edaphic factors), which determine chiefly the type of formation upon any given area. Omitting from consideration practically all of the Texas region lying to the east of meridian 97°30′, we have to deal with an area covering in its greatest north-south dimensions 10.5° of latitude (from about 26° to 36.5°), a fact of no small significance in climatic zones; and in its east-west extent 9° (from 97.5° to 106.5°), a distance sufficient to carry the western border into the Pacific zone.

CLIMATIC AND EDAPHIC FACTORS.

TEMPERATURE.

In the facts that the southernmost point of Texas is at sea level and borders on the Gulf, and is but 26° north of the equator;

[1] U. S. Geological Survey. Texas folio. 1900.

[2] Proc. U. S. Nat. Mus. 8:—. 1885.

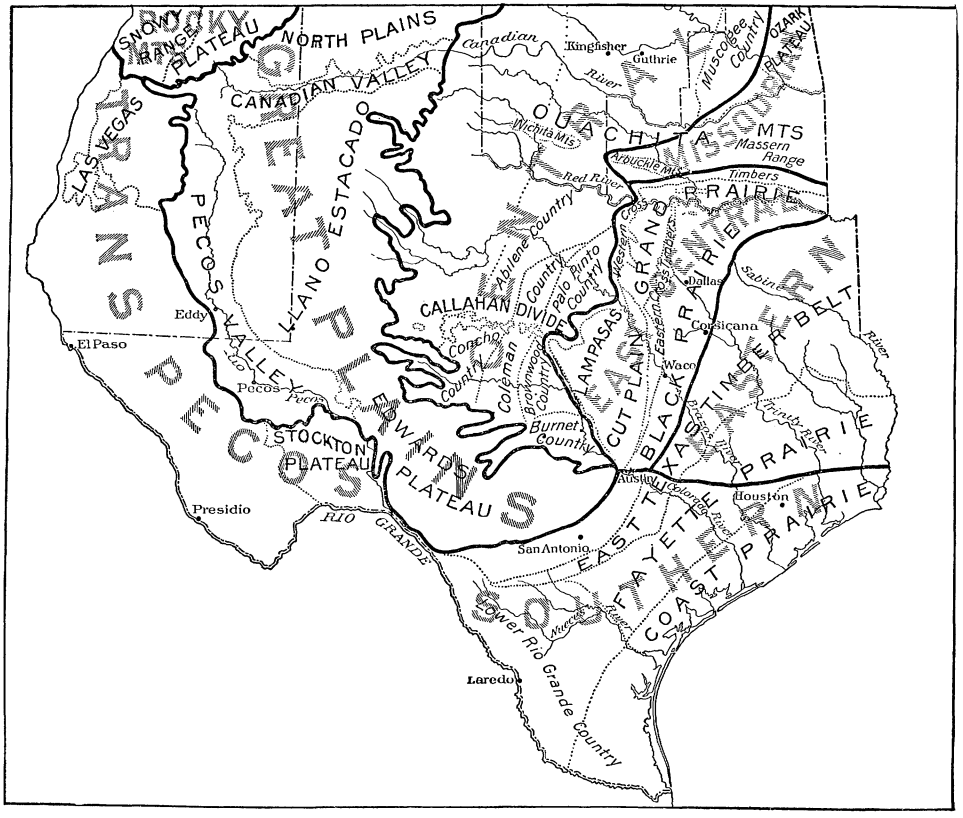

FIG. 1.—Physiographic provinces and minor subdivisions of the greater Texas region.—From Hill's Phys. Geog. Texas.

that the northernmost part is 10.5° removed from this, is at an elevation of 5000 feet, and directly exposed to the extremes of continental climate; and that in the latitude of 32° a mountain mass reaches the height of 9000 feet; we have an indication of the range of annual temperature for the region under discussion. The temperature conditions of the lower Rio Grande valley from October to April are about the same as those of the middle third of the Florida peninsula. Those of the Staked plains above 4000 feet are about the same as those of the southern half of Kansas, Missouri, and Illinois. Again, the daily

extremes, which are reflected in the structure of species, stand out most significantly in a comparison of two extreme points. The greatest daily fluctuation at Galveston is 5 to 7°F. in April; at El Paso 25 to 27° in June–July. During the February norther of 1899, points on the Staked plains above 4000 feet registered more than 20° below zero, and it was 12° above at Brownsville on the same date. These figures indicate the extremes which may occur to bring about a periodic reduction of the Austral flora. The following temperature zones as measured by the flora prevail in the western Texas region.

DILUTE XEROPHYTIC TROPICAL.—This can be recognized only in the extreme southern part of the Rio Grande embayment, especially in the present Rio Grande valley. The mean annual temperature of the valley, however, from Laredo to the mouth, is 73°, slightly below that of southern Florida. The monthly means correspond to those of the middle part of the Florida peninsula from September to March, except the January mean which falls some degrees below. The summer means rise much higher than in any part of Florida. A record of sixteen years at Brownsville showed a minimum temperature of 18° (the minimum in February 1899 was 12°) and five years without frost. At Indianola a record of fifteen years showed a minimum of 15° and four years without frost. Probably a freeze severe enough to kill tropical woody vegetation occurs in periods of ten to twelve years. The fatal temperature for tropical plants in this region is that due to the northers, which bring abnormally low temperatures suddenly, and not infrequently during the growth season. The actual poverty of a tropical flora, however, is due equally to the aridity of the region. The floral affinities of the tropical element are with the Neotropical Gulf zone, and are a part of the Tamulipan division of this zone.[3]

The following species, as illustrations, will be recognized as belonging to groups of chiefly tropical distribution, but even some of these pass into northern and southern subtropical territory: *Sabal Adansonii*, *S. Mexicana*, *Monanthochloa littoralis*,

[3] MERRIAM, C. H.: Life zones and crop zones, p. 52.

Jatropha macrorhiza, *J. multifida*, *Janusia gracilis*, *Aspicarpa hyssopifolia*, *A. longipes*, *Galphimia angustifolia*, *Malpighia glabra*, *Amyris parvifolia*, *Helietta parvifolia*, *Schaefferia cuneifolia*, *Serjania incisa*, *S. brachycarpa*, *Urvillaea Mexicana*, *Wissadula mucronulata*, *Hermannia Texana*, *Melochia tomentosa*.

SEMITROPICAL.— The tropical elements, which are but faintly indicated even in the southernmost part of Texas, quickly merge into a semitropical zone, which is visible and persistent even to the cañons on the border of the plains region, and especially up the Rio Grande into the Great Bend and its side cañons, and in the lower Pecos cañon, and this in spite of the great preponderance of Sonoran species of the Lower Austral. The range of *Acacia Farnesiana* and *Parkinsonia aculeata* would represent fairly the area of this zone outside the Rio Grande valley. A number of the species included in genera cited for the tropical portion extend also over this area. It is further indicated by such genera as Guajacum, Mortonia, Pistacia, Peganum, Ascyrium, Persea, Myrica, Balodendron (listed by V. Bailey from Corpus Christi), Cardiospermum, Castela, Choisya, Hermannia, Ayenia, Corchorus, and Malachra.

LOWER SONORAN.—The Lower Sonoran elements so pervade the regions containing tropical and subtropical species as to be by far the dominant flora, and to constitute the characteristic formations. If the Lower Sonoran division of the Lower Austral zone be counted from the 98th meridian in Texas, it exists in several grades of purity or intensity over the following provinces, varying with differences in temperature, moisture, and soil: (1) the Rio Grande plain, especially interior to the tropical and subtropical divisions; (2) the erosion mountainous portion of the Edwards plateau; (3) the central plains of northern Texas (including the cañon of the Canadian river across the Staked plains); (4) the Staked plains below 3500 feet and the adjoining plateau prairie to the south; (5) the Toyah basin; (6) the bolson plains and mesas of trans-Pecos Texas; (7) the Stockton plateau and slopes of the Guadalupe, Davis, and other mountains at the north up to about 4000 feet, and the slopes of

the Chisos and other mountains in the Great Bend up to 6000 feet.

Of these several provinces, each of which possesses distinctive floral or physiological conditions, the Rio Grande plain is clearly related to the tropical and the subtropical in its prepon-

FIG. 2.— Geology of the greater Texas region; *1*, Older Granites; *2*, Palaeozoic and Mesozoic; *3*, Cambrian and Silurian; *4*, Carboniferous; *5*, Permian; *6*, Jurassic; *7*, Lower Cretaceous; *8*, Upper Cretaceous; *9*, Non-marine Tertiary; *10*, Marine Eocene; *11*, Coast Neocene; *12*, Later igneous.— From Hill's Phys. Geog. Texas.

derance of Mimoseae and Caesalpineae, of Rhamneae, Zygophyllaceae, Rutaceae, Simarubaceae, Malvaceae, Euphorbiaceae, Nyctaginaceae, and similar groups. The central plains of the north, on the contrary, possess a minimum of these groups, but more which are peculiar or common to the central prairie plains of Kansas, Missouri, Indian Territory, and Oklahoma, such as Compositae (certain subfamilies), Papilionaceae, Onagraceae, and others. The identity of plant formations, however, as

exhibited in their general aspect, is the most convincing demonstration of the identity of this region with the northern prairies, and its small affinity with the southern ones. The cultural possibilities still further emphasize the extremes of these two divisions of the Lower Sonoran zone. As regards moisture conditions, both are transitional between Austro-riparian and Lower Sonoran, but the Rio Grande plain is in the zone of rice, cotton, sugar cane, of fruits like the fig and pomegranate; while the northern prairie province is in the belt of corn, wheat, and oats, and of such fruits as the apple. In short, the two provinces are transitional both as to temperature and moisture zones, the Rio Grande to the semi-arid and arid tropical, the central prairies to the Upper Sonoran and Carolinian zones.

The extreme in the direction of Lower Sonoran arid conditions is reached in the bolson desert provinces of trans-Pecos Texas. Certainly westward of the prairie plains of the Stockton plateau one is within the arid plateau province of that part of the Lower Sonoran zone, which then prevails westward to the Pacific. Indices of this arid province are the Yucceae, Agaveae, Cactaceae, and genera like Fouquiera, Larrea, and Flourensia. Elements of this extremely arid portion overlap to some extent portions of the Edwards plateau and of the south debris slope of the Staked plains, as will be seen subsequently. Finally, the entire area covered by the Lower Sonoran provinces is occupied by the single and generally dominant *Prosopis juliflora* (mesquite), which, though dependent upon certain peculiarities of soil structure, is absent from no considerable portion of the zone, and in its growth and occurrence reflects the measure of climatic conditions prevailing in the several provinces. This species marks well the transition from Lower to Upper Sonoran on the Staked plains.

Upper Sonoran.—This zone occupies the Staked plains and Panhandle above 3500 feet, the higher slopes and summits of the Guadalupe (except the highest points in the range), Davis, and other northern mountains above 4000 or 4500 feet, and of the Chisos mountains in the Great Bend above 6000 or 7000

feet. The summit of the Staked plains above 4000 feet has, as regards temperature, the climate of the southern half of Kansas, Illinois, and Missouri; but on account of low average rainfall and prevailing high southwest winds it has the characteristics of the high plains climate of western Kansas and Nebraska. In trans-Pecos Texas the Upper Sonoran zone is a series of islands represented by the isolated mountain summits rising out of the Lower Sonoran zone.

TRANSITION ZONE.—The highest peaks of the Guadalupe and Davis mountains possess a considerable number of transition herbaceous and shrubby species ranging north in the mountains of Montana and Washington, beside forest tracts of *Pinus ponderosa*, *P. flexilis*, and *Pseudotsuga taxifolia*, which are typical transition forests.

FLUCTUATIONS IN ZONAL BOUNDARIES.—If we accept the law of temperature control "that the distribution of boreal species southward is limited by the mean temperature of a few weeks during the hottest part of the summer," those annuals which begin their activity at a relatively low temperature, and complete their vegetative and fruiting period before the approach of summer temperature, would enjoy a distribution far within the Austral regions. To state the case differently, within the Lower Sonoran or semi tropical zone the lower temperature prevailing during February, March, and April, in which certain boreal species complete their period of fruition, would be for such species as truly a boreal zone as if they completed their fruition period during April, May, and June in correspondingly higher latitudes. This fact can account for the presence of such species as *Evax prolifera*, *Draba cuneifolia*, *Anemone Caroliniana*, *Corydalis aurea*, *Linaria Canadensis*, and others, within the borders of the semi-tropical zone. These all come into flower in the last half of February. This also explains how many prairie annuals, which are so abundant in their season as to give the dominant tone to the vegetation, may appear in this way successively over the whole Great plains area and south to Brownsville, or more frequently over the central prairies of Kansas, Missouri, and

Indian Territory to the southern extremity of the Rio Grande plain.

MOISTURE, WIND, AND LIGHT.

MOISTURE.

RAINFALL.— Beginning with an average fall of about thirty inches at the 98th meridian, the annual rainfall of the west

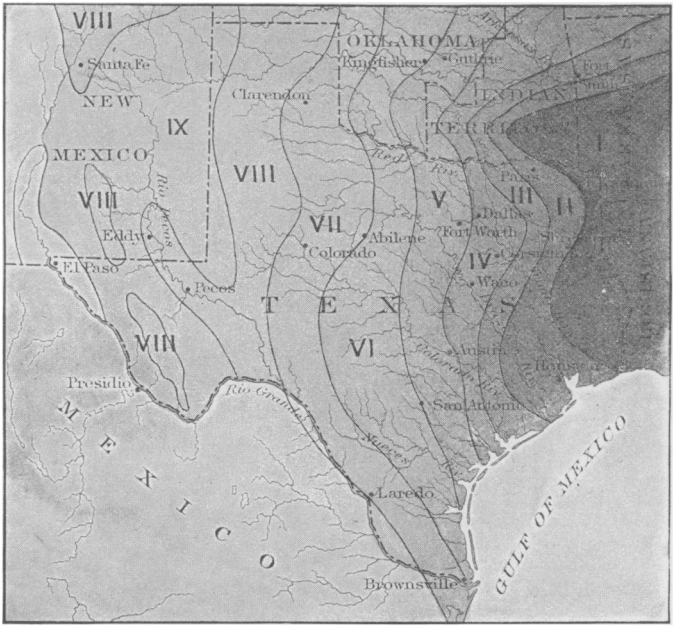

FIG. 3.— Precipitation in the Texas region: *I*, over 50 in.; *II*, over 45 in.; *III*, over 40 in.; *IV*, over 35 in.; *V*, over 30 in.; *VI*, over 25 in.; *VII*, over 20 in.; *VIII*, over 15 in.; *IX*, over 10 in.— From Hill's Phys. Geog. Texas.

Texas region decreases to nine inches at El Paso. This decrease is in general so uniform that the state may be divided into north and south zones of precipitation of five inches difference in the annual amount. The organization of vegetation with respect to moisture emphasizes these zones. The greatest interruption in their north-south equality occurs in the Guadalupe and Davis mountains, where the rainfall on the summits is fully double that of the bolson plains between the ranges (*fig. 3*).

Of equal importance with the total quantity of rainfall for plant life is its seasonal distribution. Even in the eastern part of the area this is irregular and spasmodic, although a sufficient quantity falls on the average to maintain a fairly large percentage of mesophytic species of the Mississippi valley and Gulf regions (Carolinian and Austroriparian zones), and to insure reasonable certainty of yield from cotton, corn, wheat, and oat crops. But the vegetation west of the 98th meridian bears the marked individuality of the Lower Sonoran zone in its physiological adjustment to arid conditions.

Texas lies in a peculiar position with regard to atmospheric movements, which may account for the periodic and excessive variations in seasonal and annual rainfall. The El Paso region is clearly within the Pacific-Lower Californian field of climatic influence, while the Rio Grande plains province is mostly in the Mexican climatic zone. The Great plains type of rainfall predominates over the Staked plains, and generally far into the center of the state. The Gulf type scarcely extends west of the Balcones escarpment and Grand prairie, but occasionally it carries a season of high rainfall well toward the central provinces, as during the season of 1900 (*fig. 4*).

The mean annual rainfall at Austin is 38.88 inches. Its lowest record is 18.33 inches in 1879, and its former highest record, 51.79 inches in 1888, was exceeded during 1900. The rainfall from January 1 to November 1, 1900, reached 51.19 inches. This is a fluctuation equal to the total mean. The fluctuation between Gulf and Mexican type is shown in a remarkable degree at Brownsville, where the mean is 31.52 inches, the minimum 8.88 inches in 1870, and the maximum 60.06 inches in 1886, a variation of 167 per cent. of the mean. The amount of rainfall in a single month and its departure from the monthly average may be excessive. In the last case cited (Brownsville), the rainfall for September 1886 was 30.57 inches, or 23.27 inches above the September mean. The June rainfall at Fort Clark in 1899 was 22.32 inches, or 19 inches above the mean, over 75 per cent. of this excess falling in twenty-four hours. It thus appears that

not only are the fluctuations extreme, but that a large percentage of the season's rainfall may be precipitated in two or three heavy thunderstorms. The effect of the consequent erosion is of significance for vegetation under certain soil conditions, as for example in the Red beds province, and in other places where too heavy pasturing has bared the ground of the soil-

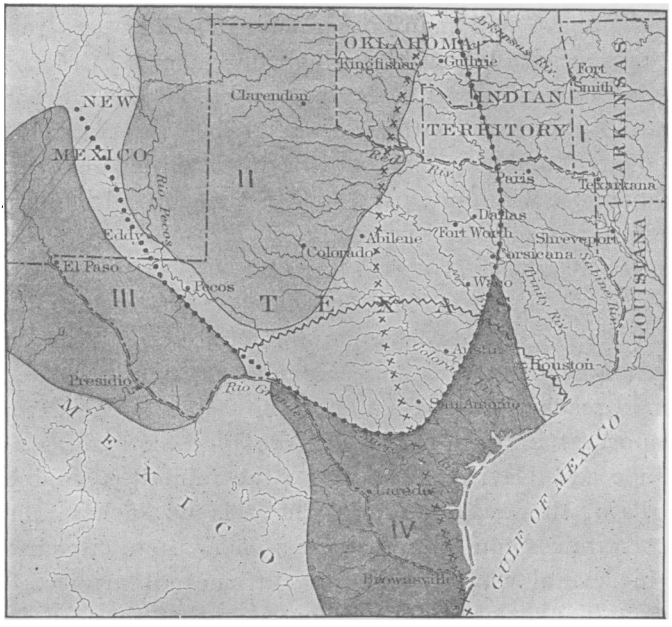

FIG. 4.— Types of rainfall in the Texas region: *I*, Gulf; *II*, Great Plains; *III*, Yuma; *IV*, Mexican; ×××, western margin of Gulf; ..... southern margin of great plains; ~~~~~, northern margin of Mexican.— From Hill's Phys. Geog. Texas.

building grasses, as in the upper Rio Grande province. From these irregularities it follows that the vegetation has adapted itself to continuous drouths, and to sudden transitions from growing to dormant periods and back again.

SOIL MOISTURE.—The relation of rainfall to vegetation after its precipitation is of importance, and is largely a result of geological structure and relief. A single illustration will suffice. In traversing the Rio Grande plain from Uvalde to Eagle pass

in April of the dry spring of 1898, all the country covered by compact clay silt wash from the Balcones escarpment, being soil from which rainfall quickly flows away, was practically bare of grass and herbaceous vegetation. Even the streamway timber vegetation was shedding its leaves. On the outcrop ridges of Eocene sand, where all precipitated moisture had been retained and kept available, the landscape was fresh with grasses, composites, legumes, and many other annuals. This was repeated in a more noticeable degree during the same month in passing from Eagle pass to Carrizo springs, where again the compact clay and silt alternated with wide stretches of Eocene sand. The availability of underground water in the sand beds is evidenced by innumerable wind pumps, while in the clay silt country the surface water is collected in ponds.

HUMIDITY AND EVAPORATION CAPACITY.—The conditions of air moisture in the west Texas region have an important bearing upon the vegetation. As may be noted in *fig.* 5, illustrating evaporation capacity, this increases in proportion to the decrease in rainfall, reaching its maximum of 80 inches at El Paso, with this important exception, that in the high mountains of the Guadalupe and Davis ranges, where the rainfall is double that at El Paso, the evaporation capacity is 90 inches annually. This moistureless condition of the air under these circumstances reacts in several ways to pile up extremes of aridity. First, there is no blanket of vapor or clouds, so that the force of the sunlight is intense: and second, temperatures become extremely high during the day, and because of rapid radiation sink to a low point at night, except in the region of the Gulf winds. Under such circumstances the adaptations in the structures of plants are most strongly marked. It follows that moisture determines, far more than any or all other factors, the structural aspects of the flora.

Moisture determines, as we have already seen, degrees of intensity of the Lower Sonoran flora. Lack of moisture has diluted the tropical elements, the Gulf zone semitropical, the Austro-riparian and Carolinian floras in the east, and the mountain

transition flora in the west, all of which gradually disappear in the prevalence of intensely xerophytic species. On the other hand, increasing aridity has intensified the Mexican semitropical, the south plateau Sonoran flora, and the Great plains flora. The transition from the eastern mesophytic to the western xerophytic zones presents interesting phenomena of geographic range. For

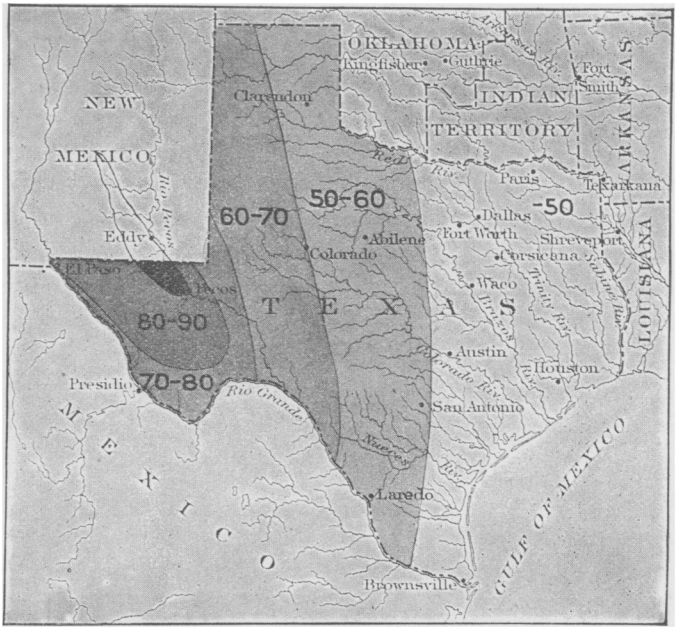

FIG. 5.— Evaporation in the Texas region, in inches per year.— From Hill's Phys. Geog. Texas.

example, *Juglans nigra* is succeeded by *J. rupestris*, and *Juniperus Virginiana* by *J. sabinoides* and other species. Prominent Austro-riparian and semitropical species, like *Pinus palustris*, *Magnolia grandiflora*, and *Persea Borbonia*, abruptly stop; and xerophytic Lower Sonoran and semitropical species as abruptly begin, as *Prosopis juliflora*, *Acacia Farnesiana*, and *Parkinsonia aculeata*.

WIND.

The enormous expanse of the plains area in Texas and the daily heating of a thinly covered soil promote movements of

air of very effective velocity, especially during the most active growing season. The average velocity per hour for the Gulf coast at Port Lavaca (observations taken formerly at Indianola) from January to July is fourteen miles, at Fort Elliott in the Panhandle 13.4 miles, at Abilene in the central plains province 11.9 miles. The prevailing direction in these cases, and for all the area east of the Staked plains and the Pecos river, is from the southeast, except for Fort Elliott, where the winds during January, February, and March are from the northwest (of little significance as they precede the season of growth). On the summit of the plains the velocity is even higher, and the prevailing direction during the growth period is from the southwest and west. The winds of trans-Pecos Texas are also prevailingly southwest, so that for the Staked plains and trans-Pecos Texas the winds are relieved of their moisture by long passage over arid plateau country. East of the Staked plains and of the Pecos the prevailing wind is from the Gulf.

The significance of these winds for plant life is as follows: (1) in their mechanical impact upon plants; (2) in rapidly carrying away moisture; (3) in erosion and transportation of soils; (4) in moisture-bearing capacity. As to the first point, the result is to dwarf and minimize arborescent growth, and to exclude plants with broad foliage, or herbaceous plants of tall growth. Trees on the coast prairie always incline strongly to the northwest, as does also the prairie mesquite in the Abilene country. On the summit of the plains, even with irrigation, groves of trees are very difficult to start because of the whipping, and bruising, and breaking of young branches and foliage by the wind. On the coast prairie windbreaks are essential in cultivating orchards. At Alvin the orchards where unprotected by windbreaks dwindle away toward the southeast exposure.

As the final effect of high wind is to promote rapid transpiration, this danger results in plants with sparse foliage of small sized leaves. This is brought about also by prevalent or frequent extremes of aridity due to intense heat and lack of precipitation throughout the region of high wind velocity.

In the third place, the transporting power of the wind has a marked influence on the selection of species. First, by dune formation and the assemblage of characteristic dune species, but particularly of sand-binding plants. This is true on the Gulf and on sandy stretches in the interior (Staked plains sand area, Rio Grande sand areas). In the second place, by the erosion and blowing away of soil-forming débris which tends to accumulate upon and modify arid patches, thus rendering the substratum almost naked rock or chalk or gravel, and inducing a new vegetation. The process of wind denudation is much more common, since after over-pasturing and dry weather thousands of acres are left unprotected by soil-binding grasses, and the soil being often a loose, fine silt, or adobe of sandy nature, is easily lifted by even a moderate breeze. It was shown above that such soils are also greatly washed by the heavy rainstorms which come at irregular periods.

As to the moisture-carrying capacity of the winds, of course the Gulf wind starts inland fairly well saturated, but meeting constantly warmer and drier conditions its relative humidity is greatly decreased, so that a precipitation of the moisture of a direct Gulf wind is not common.

LIGHT.

It would be of value if there were definite quantitative data as to the effect of light upon the vegetation of western Texas. Undoubtedly its effect is felt in the general dwarfing of the vegetation, and is plainly seen in the peculiar types of arboreal vegetation, as the "orchard tree" outline of crown. This is observed characteristically in the mesquite, but the live oak, water elm, post oak, and hackberry also assume this form. The mountain cedar is a compact low tree of oval or spherical outline, with diffuse branching from the ground. Undoubtedly the dull grayish-green of the vegetation is largely due to the effect of light, as there are probably fewer chloroplasts in any given assimilative cell. Also there are cases where the epidermis is so constituted as to diffuse light rays by reflecting facets, as appears to be the case in many cactuses and agaves.

A series of experiments was conducted by Professor H. Ness[4] to determine certain differences between the growths from seed of the same varieties of corn grown at Ithaca, New York, and at College station, Texas. Among other things, he showed conclusively that in Texas all varieties have a much shorter stalk than in New York, which he concluded was due to differences in the relative intensity of light, thus verifying previous observations.

In the trans-Pecos country the percentage of sunshiny days is nearly as great as in the maximum region of central and southern California. Where the Gulf winds prevail, there is a relatively high percentage of cloudiness and humidity, which reduces the total light effect. But the percentage of sunshiny days does not express the real effect of light upon vegetation in this region; it is the actual intensity or quantity present at any given hour of sunshine. The sun's rays are almost at the maximum intensity during the vegetative season, and their intensity is undiminished by atmospheric moisture over most of the area. Furthermore, the rock, gravel, chalk, or clay, lacking a green covering of vegetation to receive and subdue the light, reflect it in blinding intensity. Partly on this account, and partly because of lack of air, moisture, and rainfall, there is no densely shading vegetation characteristic of the region except in well-watered cañons. The dominant mesquite, huisache, retama, and numerous other Mimoseae, with their feathery foliage only loosely filter the light, but do not interrupt it. The junipers and pines of the hills and mountain slopes of the Lower Sonoran zone are also relatively shadeless trees, and the scrub oak and the chaparral species generally cast only a thin shade. As a consequence, the shade loving plants west of the 98th meridian are confined to moist crevices or watered cañons and sheltered water courses. This feature is emphasized by the absence of shade loving pteridophytes, and the general occurrence on the exposed rock of eroded areas of sun loving ferns and club mosses.

[4] Transactions Tex. Acad. Sci. 2: [part 1]. 1898.

PHYSIOGRAPHY AND GEOLOGY.

In general the "greater Texas region" of Hill, to borrow his illustration, lies as a stairway leading from the coast by a succession of steps to the cordilleras. On the west there is a balustrade formed by the southern prolongation of the Rocky mountain cordilleras and plateau; on the north the balustrade is the Ouachita system, extending east and west in Oklahoma and the Indian Territory. The slope leads up from the Gulf level to 5000 feet at the base of the cordilleras at the northwest. The geological areas are the "stair steps," speaking approximately. Beginning with the latest, they are the coastal plain (coast Neocene), the Fayette prairies (marine Eocene), the Black prairie (Upper Cretaceous), the Grand prairie (Lower Cretaceous), the denuded areas of the Granite country, the Carboniferous sandstones and shales, the Red beds (Permian), and finally the Llano Estacado (non-marine Tertiary). The "balustrade" of the trans-Pecos mountains and plateaus (except the Stockton plateau, which is part of the Great plains area) is quite distinct from the regions just cited. The tilting of the strata and weathering and erosion have given rise to diverse physiographic features, which are in close harmony with the geologic structures and strongly reflected in the vegetation (*figs. 1, 2*). Since the edaphic factors stand out so prominently in determining plant formations, they will be given a proportionate prominence in this discussion. In general, the physiographic and geologic provinces as defined in Hill's *Physical geography of the Texas region*[5] are employed in this paper, except that the Great plains region is made to include all east of the front ranges of the trans-Pecos Texas and north of the Rio Grande plain, with meridian 97.5° as an arbitrary boundary on the east. This is done because the physiographic ecology of the vegetation is most significant when it is borne in mind that the present conditions are but a stage in the leveling down of a former higher plain which covered this entire area, and whose remnants we have in the Great plains proper, the Edwards plateau, and buttes

[5] Topographic atlas of the U. S. Texas folio.

and mesas scattered all over the central prairie provinces. The process of leveling is in various stages in different places, such as deep dissections in the southern half of the Edwards plateau, undulating prairie in the Grand prairie province, a flat plain in the granite area with rugose surface caused by projecting granite

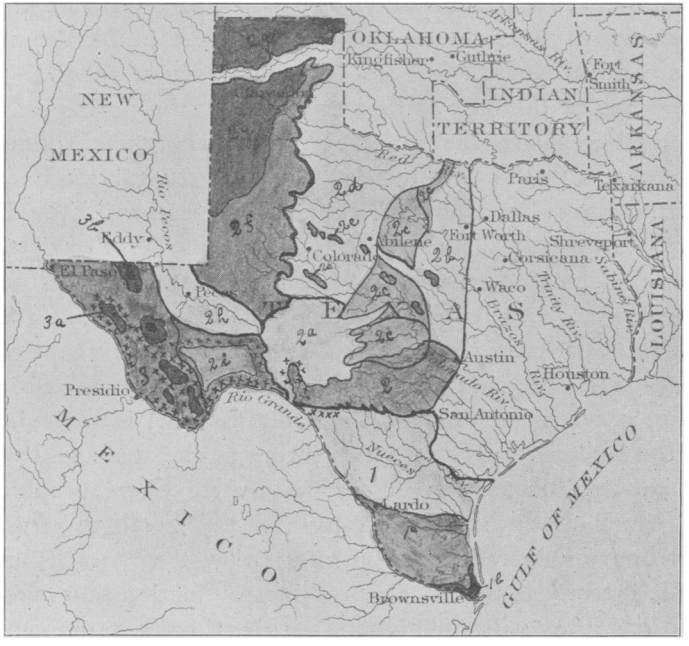

FIG. 6.— Vegetation provinces of the west Texas region, chiefly on the basis of physiography and geology: *1* to *1b*, Rio Grande plain, chaparral region (*1*, Lower Sonoran transition to Austro-riprarian and semi-tropical; *1a*, semi-tropical, *1b*, dilute xerophytic tropical); *2* to *2i*, Great Plains region (*2*, Edwards plateau xerophytic timber province; *2a* Edwards plateau plains, grass formations; *2b* Grand prairie transition, between Lower Sonoran and Austro-riparian, grass formations, adobe vegetation, butte and escarpment timber; *2c*, post oak formation on granite, Carboniferous, and upper cross timber sands and gravel; *2d*, grass prairie formations of Red beds province, Lower Sonoran with elements of Upper Sonoran; *2e*, erosion remnants (buttes) of Staked plains and Cretaceous area, xerophytic timber; *2f*, Staked plains Lower Sonoran; *2g*, Staked plains Upper Sonoran; *2h*, Toyah basin, Pecos valley province; *2i*, Stockton plateau province, grass formation and Yucca belts); *3* to *3b*, provinces of Rocky mountains and south plateau slope (*3*, extreme Lower Sonoran, bolson flora, chaparral, Yucca-Agave-Cactus formations; *3a*, Upper Sonoran; *3b*, Rocky mountain transition).

masses. These various phases in the process of wearing away the former plain and leveling up the denuded areas constitute the edaphic conditions which determine the general types of vegetation formation prevailing in the several provinces. These might serve almost equally well as designations of vegetation provinces. The provinces here referred to are the following: the Rio Grande plain; the Great plains region, embracing the Edwards plateau, the Grand prairie, the granite area, the Carboniferous area, the Red beds prairies, the Staked plains, Toyah basin, and the Stockton plateau; the south plateau of the Rocky mountains, embracing isolated mountain masses and cañons, grass plains, and bolson deserts.

PLANT FORMATIONS.

The classification of plant formations employed in the following pages is based chiefly upon local conditions of soil, geologic structure, and physiographic features, that is the formations are edaphic. For example, rock formations, forest formations, and salt basin formations exist because of local soil structure or content. In the case of grass formations, climatic factors, especially moisture, play an important part, not only in determining the existence of a grass formation as opposed to a forest formation, but also in determining the special association of species in the different formations. For example, although the physical structure of the Staked plains is most favorable to forests, such formations are naturally excluded by scantiness of rainfall; and in the Rio Grande plain the pigmy forest of chaparral succeeds the dense mesophytic forests of the Atlantic coast plain because the factor of moisture has suffered so great reduction. In every case the particular type of formation existing upon a given local area depends upon the local conditions of physiography and geology. For example, of the forest formations the post oak type is always present upon sand and gravel beds. The streamway cañon, hill bluff, and escarpment forests are all products of the soil conditions prevailing where they occur; for, although their differences are due to differences

of moisture, these are a result of the physiographic and geologic peculiarities, and may occur independently of rainfall and humidity.

The plant life of the region in general may be included in the following formations: (1) grass formations, (2) woody formations, (3) succulent formations, (4) rock formations, (5) halophytic formations.

I. GRASS FORMATIONS.

The consideration of plant formations in western Texas may begin appropriately with the grass formations, for, excepting only the highest mountain summits of trans-Pecos Texas, the climate is a "grass plains climate," and the grasses may be said to form the matrix of the vegetation of the region. Texas is thought of commonly as a land of grasses, and properly so as regards the portion considered in this paper. Under what may be called natural conditions, to distinguish them from conditions which prevail under the present era of exploitation, the grass formations held their own in the perpetual struggle against woody vegetation. With the advent of the cattle business, however, this advantage was lost, and the present is an era of the rapid encroachment of timber formations. These phenomena and their causes will be specially considered in a subsequent paragraph. Mention is made of the matter here to explain that in discussing the grass formations as they now exist we are dealing with a vegetation which, though still the dominant type, has not only a more restricted distribution than formerly, but is undergoing perceptible changes, not only in restriction of its area as the dominant formation, but in the association of species within the formation.

Along with the grass plains vegetation will be discussed those types of formation which, though distinct enough as formations periodically, never for more than a brief period form the dominant vegetation, and are in every case distinctly a prairie feature. Such are the prairie annuals (generally mesophytes) and the lignescent perennials (tropophytes).

In the present discussion the formations are taken up by geologic and physiographic provinces, because they seem not to be distinguished so much upon floristic as upon ecologic grounds. Temperature conditions will be seen to paly a rôle as between a province in the extreme south and one in the extreme north, but even then chiefly in the floristic content of the annuals and lignescent perennials of the prairie formations. Again, the breadth of area from east to west, following the lines of decrease in rainfall, gives the grass formations of the eastern provinces a physiognomy differing from that of the extreme western. Finally, as previously mentioned, since edaphic factors exert such a marked control upon formations, the consideration of the grass formations by provinces will give the full force of these factors.

A preliminary word may be said in reference to the grass formation of the region as a whole. It was stated above that the climate of the region is a grass plains climate, and that the grasses form the matrix of the vegetation, this being true even where they are not the dominant element. Taking the region as a whole, there is a wide range of climatic (hydrometeoric) conditions between the east and west boundaries. But even in the province of greatest rainfall, climatic conditions, together with geologic and physiographic conditions, result in a decidedly xerophytic vegetation. The grass vegetation is the chief exponent of the xerophytic conditions, and certain ecologic types of grasses are found through the entire region, as *Bulbilis dactyloides*, the specifically designated "buffalo grass." Throughout the entire region, also, the dryness of air and brilliancy of sunshine cause adaptations to rapid transitions from active growth to dormant conditions, great quantities of nutritive materials being stored in the dormant parts.

THE RIO GRANDE PLAIN.

PHYSIOGRAPHY AND GEOLOGY.—The area here included in the Rio Grande plain is really the continuation of the Atlantic coast plain west of the 98th meridian. It is in general a triangle,

whose vertices lie at San Antonio, Del Rio, and Brownsville. At the north, along the base of the triangle from San Antonio to Del Rio, the plain ends abruptly at the southern margin of the Great plains region, which is here marked by a sudden downfall, the Balcones fault escarpment, which here has an altitude of about 1000 feet. From the foot of this escarpment the plain slopes gradually to Gulf level. The Rio Grande plain of geologists, called also the Rio Grande embayment, is described as a constructional plain lying between this escarpment of the plains and the east front of the Mexican cordilleras. Its surface consists of the sheet flood débris of these two border regions, and its individuality, as distinct from the Atlantic coast plain eastward, lies in its construction and its surface weathering under far drier conditions than those which prevail eastward.

The sheet flood débris from the margin of the plains does not cover all of the Rio Grande plain as here defined. The flat coast prairie with its compact clay structure still extends along a narrow belt toward the lower Rio Grande. From Brownsville northward to the middle of the region extend vast sand plains, tongues of which reach well up toward the escarpment border. The flood débris lies in coarser or finer beds over the northern half of the plain, with exposures of arid clays, flat silt plains, or ridges of coarse gravel. Add to these features the basalt extrusions both along the northern margin and in the southern sand plains, and the streamway erosions through the various deposits, and we have the factors which not only combine to determine different types of grass formation, but have also figured prominently in favoring the encroachment of the woody vegeation, chiefly the chaparral formations.

CLIMATIC CONDITIONS.—The temperature conditions are of great significance to vegetation in this province, but only indirectly do they react upon the character of the grass formations. This indirect control consists chiefly in permitting the occurrence of woody species that require high annual temperature (Mimoseae for example), which, with certain artificial barriers removed, the burning of the grass notably, are capable of

waging a successful struggle against grass vegetation. A further result of temperature conditions upon the grass formation is to determine, in conjunction with moisture, the floristic content of the subordinate elements in these formations — the mixture of annuals and lignescent perennials with the grasses.

With regard to moisture conditions in general, scant rainfall, low humidity, and brilliant sunlight, are such as to give the grass vegetation a pronounced xerophytic structure. In this respect the grass formations agree with those of the dry plains westward, in which, with the approach of the resting period, coincident commonly with rainless periods, the aerial parts become "cured;" that is, they die, retain without loss their nutritive qualities, and remain in a good state of preservation.

Since the 98th meridian is a mere arbitrary boundary, selected with reference to separating approximately the xerophytic vegetation regions from the mesophytic, it is evident that at the eastern border of the Rio Grande plain, especially in the coast region, the grass formations approach more nearly the mesophytic structure; while at the west, along the Rio Grande, they approach the pronounced xerophytic aspect of distinctly arid regions.

With respect to the relation of grass formations to woody formations in the Rio Grande plain, the encroachment of the latter has been so vigorous as practically to destroy continuous areas of open grass formation. Much of the province is covered by impenetrable thickets of chaparral. There are broad stretches of savanna where the grass formation is more open, but the areas are studded with isolated individuals or clumps of live oak, or by open post oak formation.

On the basis of geologic structure and soils, three types of grass formation may be distinguished: (1) those of the flood débris plains; (2) those of the sand plains; and (3) those of the coast prairie. The first two are by far the most extensive and important. The third is but a slight extension of the coast prairie formation which is so characteristic on the Gulf coast from central Louisiana westward to our region.

THE FLOOD DÉBRIS PLAIN.—The flood débris from the Cretaceous formations of the Edwards plateau covers approximately the upper half of the Rio Grande plain, the altitude being from 500 to 900 feet. The level stretches of this part of the plain are covered with finer silt débris, the mesquite-chaparral plains. There are arid clay hills in the Eagle pass region, and coarse gravel and stony slopes nearer the escarpment, besides basalt cones or ridges and the outlying block of rough hills (Anacacho mountains).

Floristically the grasses are chiefly of genera making up the buffalo grass range of the plains northward. On the rougher areas, especially westward, the extreme xerophytic conditions give the aspect of the arid plains. The associated species are chiefly lignescent perennials, or perennials with thick fleshy or tuberous roots, such as *Jatropha spathulata sessiliflora* on stony or gravelly soil, *J. macrorhiza* on loose silty soil, and numerous other Euphorbiaceae and Nyctaginaceae peculiar to warmer lower Sonoran areas.

The grass formation on these areas has been very much reduced by over-pasturage, so that during drouth periods vast tracts lie quite bare of grass vegetation. In this condition pastures not wholly beset with chaparral have the appearance of fields lying beaten and fallow. So great has been the depletion of grasses that during certain dry years it was stated that from fifteen to twenty-five acres of land were required to pasture a single cow. What permanent effects on the grass formation will result upon areas so denuded it is not yet possible to say, except that the chaparral will cover the entire plain. The grasses have great recuperative power, and it is said that after periods of abundant rainfall the earth is covered again with a close grass formation. No doubt a period of rest from excessive pasturage would enable them to recapture fully much lost ground. Of course, with the presence of the chaparral and the new relations it involves, the original grass formation of open sunny plains will suffer some material changes. This subject offers a field for special investigations.[6]

[6] SMITH, JARED G.: Grazing problems of the southwest. Bulletin 16, Division of Agrostology, U. S. Department of Agriculture. 1899.

THE SAND PLAINS.—These sandy grass plains constitute the most considerable feature of the southern half of the Rio Grande plain, and arms from them reach well toward the northern boundary. In some areas the sands are so deep and shifting as to render any stable vegetation impossible. Such areas are not yet well enough known to discuss here. The conditions as regards earth moisture in the sand plains are such as to leave them covered with grass vegetation and accompanying herbaceous plants when the flood débris plains are bare of the corresponding formation. This is because they are not only better receiving areas, but the underground water is more available, for as the altitudes are low the distance to water is not great, and the open texture of the ground aids in that short distance in bringing water to the surface vegetation.

The grass formations of the sand plains are different from those of the flood débris plains in two important respects; first in the more open character of the formation, and second in their floristic content, in which the secondary elements — the prairie annuals and lignescent or succulent perennials — are especially involved. The open character of the grass formation permits an uncommonly varied growth of sand plains species. Many of the more important of these are of semitropical affinities, and hence not found in the more northerly or more elevated provinces.

THE COAST PRAIRIE.—This is typically a sod prairie with grasses and sedges of mesophytic requirements, and annuals similarly adapted to wet, low, coast lands. Such prairie is continuous between Houston and Corpus Christi, except for streamway interruptions; though in passing westward along the line of decreasing rainfall the formation gradually becomes of xerophytic stamp, and the semi-marsh land species are succeeded by grasses of the plains. Within the province of the Rio Grande this formation passes into that of the sand plains.

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[*To be continued.*]